

Article

Sustainable Mathematics in Higher Education: Insights from Action Research

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Abstract

This study explores how higher mathematics education can be reoriented towards greater sustainability, thereby better preparing students to meet the challenges of the future and supporting their sustainable employability. An interpretative phenomenological analysis was conducted to explore the lived experiences of university mathematics teachers (N = 6) integrating sustainability principles into their teaching practice. Data were collected through interviews, which revealed five thematic areas: responsibility for contributing to a sustainable future, pedagogical contradictions, ways of promoting sustainability, finding community and transdisciplinarity. These themes formed the basis of strategic principles including multi-level integration, methodological and content support, professional community development and transdisciplinarity embedded in a non-linear, cyclical implementation model. Results show that effective integration requires a combination of individual motivation with systemic institutional support, access to structured resources, and collaboration across institutions and disciplines. The proposed framework not only aligns mathematics education with the Sustainable Development Goals (SDGs) but also enhances students' ability to apply mathematical tools to solve complex real-world problems, contributing to their long-term professional sustainability and adaptation to different educational contexts.

Keywords: mathematics education; sustainability; higher education; action research



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1. Introduction

In recent years, sustainable development has become a strategic priority in higher education, prompting educational institutions to rethink their curricula, pedagogical approaches and institutional missions in light of the Sustainable Development Goals (SDGs). In the context of changing global challenges, sustainable development has become one of the key benchmarks for higher education. United Nations Educational, Scientific and Cultural Organization (UNESCO) emphasizes that education should not only impart knowledge but also equip students with the competencies necessary to build a sustainable future, including systems thinking, critical analysis and responsibility for decisions made [1]. According to reports by the global Organization for Economic Cooperation and Development (OECD) “Global competency for an inclusive world” (2016), modern education should

prepare students not only for professional activities but also for active participation in addressing global challenges, including climate change, depletion of natural resources, social inequality and technological transformations. In its Education 2030 initiative, the OECD focuses on developing competencies that enable people to cope with complexity, uncertainty and the need for long-term thinking [2]. UNESCO emphasizes that education for achieving the SDGs should be integrated at all levels of education and into all subjects, including mathematics, which has traditionally been considered detached from the social context [1].

As UNESCO emphasizes, mathematics is not only present in our everyday lives but also plays a fundamental role in addressing global challenges such as climate change, resource optimization and risk prediction, making it a powerful tool for developing sustainable development competencies [3]. Therefore, the question of how higher mathematics education can be reoriented to support sustainable development becomes particularly relevant. A number of international studies, including the OECD report ‘An Evolution of Mathematics Curriculum’, confirm the important role of mathematics in developing students’ skills in systems thinking, data analysis and mathematical modelling, which are necessary for understanding and solving complex sustainability problems [4].

2. Literature Review

The concept of sustainable development in the context of mathematics education is interpreted in scientific literature from different perspectives, many of which are related to the thematic areas of this study. Research with prospective mathematics teachers revealed that they conceptualized sustainable mathematics education through three main approaches: (1) using mathematics as a major tool for communicating climate change effects, (2) developing real-world relevant environmental tasks, and (3) supporting students as critical and relational thinkers who can reflect on tensions between personal interests and environmental protection [5]. A broader interpretation of sustainability is offered by an approach that views it as a set of four key principles rather than a single definition, in order to avoid ideological pitfalls and focus on improving society. These principles include:

- Recognizing that the current state of humanity is morally unacceptable and needs to be improved;
- Understanding that human actions threaten the ability of future generations to meet their needs;
- The need for a simultaneous and systematic approach to solving global problems;
- The requirement for fundamental changes in existing socio-ecological systems.

It notes that the mathematical community is in a strong position, as a significant percentage of students study at least one mathematics course, especially analysis or statistics [6]. This echoes the assertion that mathematics education is not value-neutral: it is part of the socio-cultural environment and can either reproduce or challenge social inequalities. Sustainability in the context of mathematics teaching also means developing teaching materials based on pedagogical content knowledge to ensure deep conceptual understanding [7].

The literature contains examples of current practices that reflect the incorporation of sustainable development principles into mathematics teaching. Sustainable development topics are integrated through the modelling of real-world processes, such as the dynamics of biological populations or economic interactions. If students perceive mathematics as a modelling tool, teachers can use an “overlapping” approach, focusing the concept of sustainability on resource analysis [8]. Another approach is presented in how teachers developed and implemented three training modules on the introduction of SDGs as part of a course on mathematics teaching methodology, using the DeCoRe+ (Deconstruction-

Construction-Reconstruction) methodology, which involves rethinking and reconstructing course content based on sustainable development goals. Integration was achieved through problem-oriented tasks, project activities, work with contextualized tasks, and the creation of concept maps reflecting the connection between mathematical topics and the SDGs [9]. Tasks based on real environmental data are also mentioned, in which students analyze the growth dynamics of plastic waste as an example of applying mathematical modelling to sustainable development issues [10].

Despite growing interest in sustainability, integrating this topic into mathematics education poses a number of challenges, as discussed in several studies [5,11,12]. One of the obstacles highlighted is that the integration of sustainable development topics into mathematics teaching is hampered by academic staff's lack of knowledge about the SDGs and strategies for their implementation, as well as the widespread belief that sustainability mainly relates to other subject areas, for example natural sciences (including science education, environmental sciences/biology), social sciences and ethics [11]. This problem is compounded by another important barrier related to the lack of teaching materials for integrating sustainable development, namely the absence of suitable teaching materials. There is a weak link between existing mathematics teaching materials and real environmental and social challenges, which has required the development of new examples and approaches [13]. From a practical point of view, difficulties are also associated with limited time resources. Despite the reduction in the number of hours allocated to teaching mathematics at universities, the content of courses has remained the same or even expanded, making it difficult to include new topics, including sustainable development [12]. At the administrative level, rigid curricula and exam pressure are obstacles that make it difficult to incorporate sustainable development into mathematics teaching [5].

A number of studies describe how students perceive tasks related to sustainable development and what reactions the inclusion of this topic in the educational process evokes. For example, one observation concerns the change in students' attitudes towards algebra: they noted that studying algebraic concepts through real-life problems helped them to rethink the educational material [14]. Another study emphasizes that a seminar on modelling Education for Sustainable Development (ESD) successfully increased future teachers' self-esteem and their awareness of the potential of mathematics education and mathematical modelling in solving sustainable development problems [11]. One study found that the inclusion of SDGs in the curriculum had a positive impact on the development of academic skills. Students who studied under the new programme showed a significant improvement in problem-solving abilities compared to the control group [15]. At the same time, studies also point to certain shifts in the perception of the role of mathematical skills: young people believe that manual calculations are becoming irrelevant, since most tasks can be delegated to technology [16].

Recent studies highlight diverse and effective approaches to integrating sustainable development principles into mathematics teaching. A number of works consider mathematical modelling of sustainable problems as a key tool for developing sustainable thinking in students [17]. It is emphasized that modelling helps to structure the problem-solving process, starting with the translation of real-life problems into mathematical representations and ending with their analysis [11]. This didactic strategy underlies many approaches presented in the literature: for example, in some studies, effectiveness is achieved through the use of tasks based on real data [18], while others focus on everyday situations familiar to students [8]. Individual examples illustrate the use of tasks focused on the future professional activities of students [12] or the use of differential equations and their applications for the analysis of stable processes [19]. The integration of digital tools plays an important role in teaching. The use of digital tools for design and calculations [14] and the

use of mathematical software [20] increase student engagement and provide clarity when studying sustainable processes in mathematics. Group work and collective discussion have proven to be effective forms of organizing the learning process [18].

The literature shows a trend that teachers need centralized, accessible resources, examples, and training courses. There is a lack of ready-made materials and resources for teachers, and it is proposed to create an online platform containing successful cases and projects on integrating sustainability into mathematics teaching [18]. The importance of access to training courses, open educational resources, and examples of best practices is emphasized [20]. At the same time, it is noted that teachers not only rely on external support but also actively participate in the process themselves. For example, one study describes the participation of teachers in a project to develop relevant methodological materials aimed at integrating sustainable development into the educational process [14]. These initiatives point to the formation of a professional community interested in exchanging experience and developing methodological solutions that contribute to the successful integration of sustainable development topics into the educational process.

A number of studies examine how teachers perceive their role in preparing students with sustainable competencies and what responsibilities they feel they have in doing so. University teachers feel responsible for providing students with the knowledge, values and skills necessary to create a more sustainable world, as they consider promoting sustainable development in academic activities to be a central task of their work [20]. Teachers' awareness of their professional and civic responsibilities is manifested through reflection on their role, proposals for specific actions at the classroom and institutional levels, and interaction with families, which correlates with an advanced level of engagement [21]. Teachers see their mission as equipping the next generation with the knowledge and skills necessary to make a conscious contribution to a sustainable future. In addition, the authors note that immersing students in scenarios related to the use of renewable energy sources, waste reduction strategies, or urban sustainability allows them to understand the real impact of mathematical modelling on current sustainability issues [13]. Teachers recognize their professional responsibility to prepare students with interdisciplinary and sustainable competencies as part of their teaching mission [14]. The university as a whole sees its mission as training socially responsible specialists, and transdisciplinarity within a single educational programme is seen as an effective strategy for analyzing SDGs using mathematical methods [22].

The aim of this article is to define a strategic vision and propose an open framework for integrating sustainability into higher mathematics education in response to global challenges.

3. Materials and Methods

3.1. Action Research

Action research in education is grounded in the assumption that contemporary life is characterized by uncertainty, rapid change, and diversity. Education should react and adapt to new life conditions to prepare the new generation for life in such kind of society. That is why research, and especially research in education field cannot be studied using reductionist philosophy reducing all complex phenomena to their simplest components in such way offering piecemeal approach to research. We cannot describe education practice just analyzing isolated components of it. Rather researchers should characterize the patterns of interactions or relations between these components [23]. Teaching/learning process in its nature is complex process where we can never precisely predict its course and sequence. Action research focuses on critical reflection and inquiry about one's professional practice, to better understand them and to be able to improve their work quality [24]. The core of action research is related to the change in and improvement of the professional practice

of teachers based on the convergence of practice-oriented science and science-oriented practice [25].

When studying sustainability, it becomes essential to understand and articulate action research (1) as a unique, complex phenomenon arising from the interaction of multiple complex processes; (2) as a strategic approach that integrates research and learning across different perspectives [26]. The authors choose action research as an approach to study sustainable mathematics phenomenon in the higher education context.

Action Research Activities and Results

This action research is conducted as part of the initiative by the UNESCO Chair on Teacher Education and Continuing Education: Interplay of Tradition and Innovation in Education for Sustainable Development at Daugavpils University, Latvia. The Chair has a long-standing practice of using action research for studying lived experience [27]. Established in 2013, the Chair initiated internal structural changes at Daugavpils University, fostering the development of ESD research and the broader implementation of ESD initiatives. Following its establishment, efforts began to create a platform that positioned ESD as a strategic objective for the university as a whole. Developing the Chair's role further became evident in fostering institutional cooperation at both national and international levels, gradually emerging as a recognizable "network of networks" that fosters action research to examine education on a broader scale and engages diverse stakeholders with varied experiences and perspectives. The stakeholders for the present study include: (1) researchers specializing in ESD studies; (2) university-level mathematics teachers from Latvia, Estonia, and Åland Islands (Finland).

The action research comprised three main activities that illustrate how sustainability can be integrated into higher mathematics education. The first two activities were initiated in response to the need for higher education to address global challenges. The necessity of the third activity emerged from reflections on the results of the previous activities, highlighting the importance of expanding the methodology and deepening the understanding of the sustainability phenomenon.

The first activity. Developing the course "Green Turn with Mathematics".

The Green Turn with Mathematics course was developed in response to the growing need to integrate sustainable development topics into higher mathematics education. One of the key factors that made this initiative possible was the synergy of resources between partner universities: the academic and methodological competence of teachers in mathematics, physics and technical disciplines was combined with access to modern laboratory facilities at the Åland Islands University of Applied Sciences. This laid the foundation for a course that combined theoretical content with practical tasks aimed at analyzing real-world processes in the context of sustainable development.

The development of the course began with setting goals and formulating learning outcomes focused on developing students' skills in modelling and analyzing sustainable processes. The course was built on the Moodle platform and included interactive elements, self-assessment tasks and a modular structure corresponding to key aspects of sustainable development.

The second activity. Implementing the developed course.

The course was implemented in the spring of 2025 in collaboration between students and teachers from Tallinn Technical College (TTK) and the Åland Islands University of Applied Sciences. The training took place in four stages: first, a full asynchronous online part via Moodle, where students independently mastered key topics and completed assignments; then, a week of face-to-face training in the Åland Islands with laboratory work and data collection; then a second online phase to study the theoretical basis necessary for

analyzing the results; and finally, an in-person module in Tallinn, where students analyzed the collected data using statistical methods.

The course was funded by the internal resources of both universities, and student participation in the international modules was supported by Erasmus+ funds as part of academic mobility. An important feature was that the course was offered to students as an elective subject, which contributed to the flexibility of the curriculum and intercultural interaction in the educational environment.

Additionally, after the course was completed, a survey was conducted among students ($N = 14$), which confirmed the positive perception of the course and its value for the development of critical and systematic thinking. In the course “Green Turn with Mathematics,” students highlighted working with data and its visualization (Excel, Power BI), as well as studying energy and sustainable technologies such as solar panels and heat pumps. Students were most interested in practical tasks in laboratories with real equipment. These activities closely reflect real-world work scenarios and can thus be associated with enhancing students’ sustainable employability.

The third activity. In cooperation with the UNESCO Chair on Teacher Education and Continuing Education: Interplay of Tradition and Innovation in Education for Sustainable Development at Daugavpils University (Latvia), Riga Technical University (Latvia), TTK University of Applied Sciences (Estonia) and Åland University of Applied Sciences (Åland Islands, Finland), a developmental project was designed, submitted, and approved with support from Nordplus. The project aims to: (a) develop innovative teaching materials; (b) promote up-to-date teaching methods in higher education mathematics; and (c) apply mathematical knowledge to real-life and professional contexts, promoting sustainable mathematics education. The project starts in September 2025.

3.2. Data Collection and Sample

Interviewing is the most common way of collecting data in action research [28]. For data collection, semi-structured interviews were employed to comprehensively capture the university lecturers’ views, beliefs, and practices regarding sustainable mathematics in higher education institutions. Semi-structured interviews use a predefined set of questions as a guide for the conversation. This approach offers flexibility, enabling the interviewer to steer the discussion in a semi-open way and allowing new, relevant topics to emerge alongside the planned questions [29].

A total of six interviews were conducted with Latvian and Estonian university teachers who were involved in the action research described above. The total of 6 interviews was considered sufficient for the scope and objectives of the study. This sample size aligns with established qualitative research practices. In qualitative research, sampling is typically associated with non-probability approaches, with purposive sampling being one of the most commonly employed techniques. Unlike random sampling, purposive sampling is strategically designed to select participants who are particularly relevant to the research questions under investigation. The aim is not to achieve statistical representativeness but rather to ensure the inclusion of information-rich cases that provide deep insights into the phenomenon being studied [30].

The interviewees were selected based on the following criteria: (a) at least 3 years of experience of teaching mathematics in higher education institution; (b) has expertise in education for sustainable development (reflected in scientific publications, scientific projects dealing with sustainability issues; presentations in international scientific conferences); (c) active involvement in curriculum development or pedagogical innovation related to mathematics education; (d) practical experience in embedding sustainability concepts into teaching and learning activities. It is important to note that all interviewees engaged in

one or more of the action research activities outlined in this section. This engagement provided an opportunity to critically reflect on their experiences, including observations of students' responses and academic performance. The profiles of interview participants are summarized in Table 1.

Table 1. Demographic and professional characteristics of interview participants.

Participant Code	Country	Academic Position	Work Experience in Higher Education (Years)	Field of Specialization
P1	Estonia	Senior lecturer	11	Mathematical analysis
P2	Estonia	Associate professor	25	Analytical geometry
P3	Estonia	Lecturer	10	Linear algebra, statistics
P4	Latvia	Lecturer	3	Applications of systems of differential equations
P5	Latvia	Associate professor	10	Mathematical modelling
P6	Latvia	Lecturer	5	Applied mathematics

All the interviews were conducted in June 2025, online using the Teams platform, recorded, and transcribed. The online format for the interviews was chosen because it was more convenient for the interviewee and interviewer to find a convenient time and place for a meeting, as well as automatic interview recording possibilities. The language of interviews was the native language of interviewees to ensure that they can freely express their ideas and subtle nuances of the language are captured. It has been emphasized that the quality and intimacy of the interviews increased when they were conducted in the mother tongue of the participants [31]. Special attention was paid to the interviewer or interview facilitator choice. It was important for the authors that this person be proficient in the topic of the current study and well-acquainted with the context of higher education to prompt the interview in an appropriate way. The interviewer was acquainted with the aim and objectives of the study and interviews.

3.3. Data Analysis

The data from the interviews were analyzed using a phenomenological approach. Unlike other methods that emphasize identifying similar meanings across multiple participants or inferring broad patterns, phenomenological analysis focuses on an in-depth exploration of the structure and essence of individual lived experiences. To process the information obtained from the interviews, an interpretative phenomenological analysis was employed. After the interviews were fully transcribed, the analysis proceeded through the following four stages [32]:

1. Identifying themes within the interview transcript.
2. Establishing connections between themes by creating thematic group tables.

3. Repeating the analysis for subsequent cases—each new interview was analyzed following the two steps above. After all interviews were analyzed, a comprehensive summary table encompassing all identified themes was compiled.
4. Producing a narrative report—where the extracted themes were synthesized into a coherent narrative, illustrated with examples and supported by interpretative insights.

In such a way, Latvian and Estonian researchers were able to analyze the interviews conducted in the perspective language, later translating the summary tables of each interview in English and working together on the comprehensive summary of the interview content and producing a narrative report. To enhance the validity and credibility of the data analysis, researcher triangulation was employed. Three researchers independently coded the interview data and, through discussion, reached a consensus on the common themes [33].

4. Results

The purpose of the interviews was to explore the university-level mathematics lecturers' hands-on experience of integrating sustainability for mathematics education. After conducting interpretative phenomenological analysis, the following themes and subthemes were identified (see Table 2).

Table 2. Interpretative phenomenological analysis of university teachers' lived experiences integrating sustainability into mathematics education.

Theme	Subthemes
Responsibility in contributing to a sustainable future	Integrating sustainability principles in everyday life
	Teachers' moral responsibility
	Change in students' attitude towards real global-scale problems
Pedagogical tensions	Lack of teaching materials
	Lack of sustainability-related knowledge among university teachers
	Additional time allocation for lecture preparation
	Feeling isolated within one's institution
Ways to promote sustainability in mathematics education	Lack of methodological support
	Lack of professional development for university teachers
	A set of ready-to-use tasks for integrating sustainability issues
	Collaboration among institutions
	Engaging students in meaningful activities.
Search for community	Providing students with hands-on learning tasks
	Colleagues' support
	The role of sharing common goals
Transdisciplinarity	Mathematics as a "universal language"
	Usage of real up-to date data

Teaching at any level of education, including higher education, is not only about imparting knowledge and demonstrating subject-specific skills but also about conveying

beliefs, values, and attitudes. To effectively teach sustainability-related themes, a university teacher must possess a personal and internal understanding of the importance and relevance of the topic within the study course. This notion was also reflected in the first theme identified through interpretative phenomenological analysis, formulated as “Responsibility in contributing to a sustainable future.” As respondent P4 says: *“Part of our job in mathematics is to show that what we teach can make a difference in solving real-life challenges, especially for the future of our planet”* (P4). In order to be persuasive, a teacher must possess a deeply held conviction regarding the importance of sustainability and consistently embody these values in their professional practice. The transformation of beliefs and everyday habits does not occur within a short timeframe; rather, it is a gradual and ongoing process: *“I’ve started to notice it in myself: starting with very simple things—like excessive packing, unnecessary purchases. Especially lately, perhaps because we discuss this topic more often at work and at university—it’s like it’s become more in focus”* (P1).

Analysis of the interview data revealed several challenges related to the implementation of sustainable mathematics teaching in higher education. University teachers who obtained their education degrees more than 20 years ago were not formally introduced to sustainability-related issues during their studies. As a result, their understanding of these topics has largely developed through informal learning experiences later in their careers. Consequently, many of them do not feel confident when addressing sustainability-related themes in their teaching: *“I really lacked the necessary all-round knowledge. These questions are already beyond the scope of my professional training as a mathematician”* (P3). As in all stages of education, starting from pre-school to higher education, teachers often lack up-to-date teaching materials. This shortage is largely due to ongoing curriculum changes and continuous reforms in the education systems of both Latvia and Estonia. In the context of higher education, it is particularly important to align teaching with current labor market trends and demands in order to prepare future professionals effectively. The same applies to sustainability in mathematics education, which must also reflect these evolving expectations and societal needs. *“...it would be very useful to have access to a bank of sustainability-oriented tasks or cases. In addition, the availability of methodological recommendations on how to integrate these topics into training courses would also greatly facilitate the work”* (P2). The availability of such materials also helps reduce the time required for preparation by lecturers, which was identified as one of the key challenges in integrating sustainability into mathematics teaching in higher education.

During the interviews, it was emphasized that university teachers require goal-oriented training on the topic of sustainability. One interviewee drew a parallel with the process of learning to use new technologies, which became particularly relevant during the shift to distance learning amid the COVID-19 crisis: *“An analogy can be drawn with the way the topic of digitalization of education was developed: at that time, regular trainings and seminars were held where we learned new methods and approaches, which helped us to move in the right direction. Now it would be important to organize something similar on the topic of sustainable development”* (P1). It was also noted that university teachers often feel isolated, particularly when attempting to incorporate new elements into their teaching practice. This sense of isolation is especially pronounced in higher education, where teaching staff typically lack the strong professional communities that are more common among secondary education teachers. According to the interview participants, one effective solution is participation in joint projects, which provide opportunities to share experiences and best practices with colleagues from other institutions and countries: *“At our university, together with colleagues from the University of Åland Islands, we developed a joint course called ‘Green Turn with Mathematics’ in which we integrated the basics of sustainable development”* (P3). In exploring this topic further, the authors also relate it to the identified theme “Search for community,”

which underscores the importance of collegial support within the university, as well as the shared understanding of core values and guiding principles in education on a global scale: *“Regardless of the country, we should have a common interest, a common level of knowledge, and we share that knowledge to come to a more common standard, which gives a sense of partnership and equality in decision-making”* (P3).

Based on the information obtained from the interviews, the authors developed a figure illustrating the main challenges encountered by university teachers in their teaching practice, along with possible solutions identified through the interview data (see Figure 1).

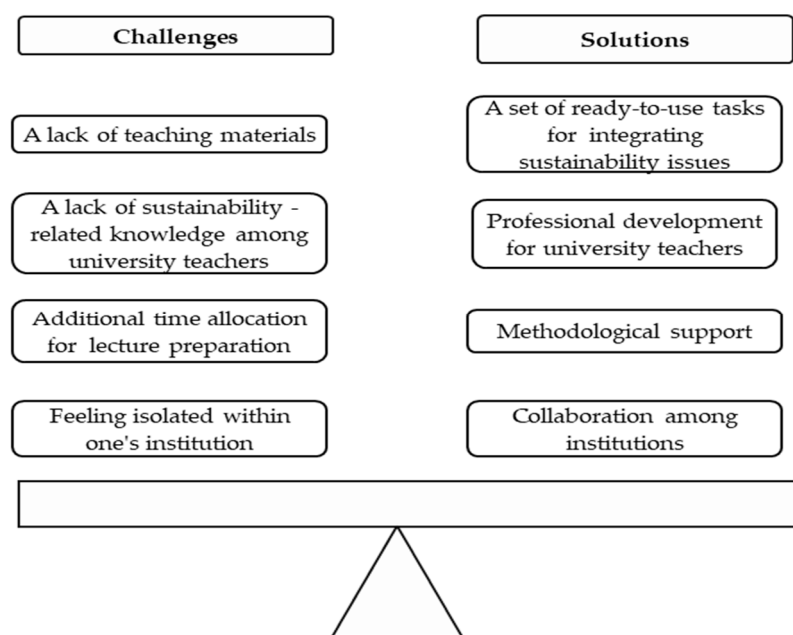


Figure 1. Main challenges and proposed solutions for integrating sustainability into mathematics teaching in higher education.

In addition to the previously mentioned strategies as deepening students' knowledge about SDGs and using hands-on activities for successfully integrating sustainability into mathematics teaching, interview participants also emphasized the importance of connecting abstract mathematical knowledge to real-life contexts and students' chosen professions: *“In this way, we managed to organically integrate the principles of sustainable development into the teaching of mathematics, allowing students to see in practice the relationship between abstract mathematical concepts and real-life challenges of sustainable development”* (P3). As P2 mentions: *“...students always react very vividly if the task is related to their specialty. If it is a vital task, but abstracted from their specialty, for example, a humanitarian one, they may perceive it as optional”*.

The authors propose that transdisciplinarity is increasingly becoming a key concept in higher education. When preparing students for their future professions, it is essential to consider that within 10 or 20 years, the specific profession they choose today may no longer exist. Therefore, students must acquire knowledge and skills that will remain relevant over time and be able to apply them in real life. Transdisciplinarity emphasizes the ability to integrate and apply knowledge from multiple disciplines in practice.

The core issues embedded in the concept of sustainability and reflected in the SDGs are societal challenges. The interviews revealed that university teachers recognize how mathematics can contribute to addressing these societal challenges. *“Maths is basically the principles of sustainable development: critical thinking, working with real problems, working with data”* (P3).

The interview findings indicated that the results were largely repeatable across the six teachers, with convergence around core themes and only bounded variation reflecting individual contexts.

Based on the conducted action research, the authors propose a framework for reorienting higher mathematics education toward greater sustainability (see Figure 2).

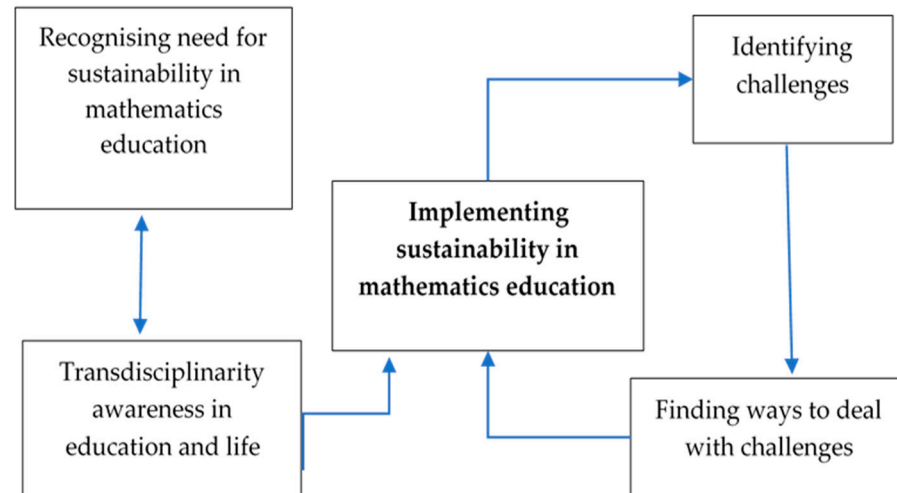


Figure 2. Framework for reorienting higher mathematics education toward greater sustainability.

The proposed framework for reorienting higher mathematics education toward sustainability is based on the findings of the current action research. In this study, the process began with recognizing the importance of sustainability in mathematics education, which naturally led to the identification of related challenges. As the research progressed, possible ways to address these challenges were explored, highlighting the significance of transdisciplinary thinking in both education and everyday life. Eventually, these insights contributed to the implementation of sustainability-oriented approaches in mathematics teaching. Importantly, the framework is not intended to be linear; the stages may occur in a different order or be revisited depending on the specific context, institutional environment, or the educator's development path.

5. Discussion and Conclusions

Study confirms the need and strategic importance of integrating the principles of sustainable development in higher mathematics education, which is in line with the global priorities outlined by UNESCO and OECD.

The aim of this study is to present a strategic vision and propose an open framework for reorienting higher mathematics education towards greater sustainability. This study used interpretative phenomenological analysis to explore how university mathematics educators perceive, experience and implement the integration of sustainability principles into their pedagogy. The analysis identified five thematic areas: responsibility for contributing to a sustainable future, pedagogical contradictions, ways of contributing to sustainability, finding community and transdisciplinarity, which describe the nuances of their personal beliefs, pedagogical challenges and strategic approaches that shape this process, laying the groundwork for a strategic vision for reorienting higher mathematics education towards more sustainable development. Based on these results and comparison with the literature, strategic principles were formulated: multilevel integration, methodological and content support, development of professional communities, and transdisciplinarity.

The first principle of the strategy is multilevel integration, where sustainability should be embedded in the curriculum both at the level of individual courses and at the level

of institutional strategy. The study emphasizes that teachers' personal conviction and awareness of their moral and professional responsibility to prepare students for a sustainable future is the most important factor in the successful integration of sustainable development principles into teaching, which is consistent with the findings of previous studies [14,20]. However, personal motivation is only truly effective when combined with systemic support, institutional strategies, guidelines, centrally developed resources and targeted courses. This combination of individual initiative and structural solutions not only facilitates the implementation process but also ensures its coherence, preventing the activities of individual enthusiasts developing in disparate directions and not forming a single, centralized vector of action for the whole community.

Methodological and content support for teachers, including access to ready-made resources, task banks, guidelines and training courses is one of the most demanded conditions for successful integration of sustainable development principles. Limited knowledge of the SDGs, lack of readily available materials and lack of time were identified by respondents as some of the main barriers. The results are consistent with the findings of previous studies and confirm these challenges [11–13]. Respondents noted that even high personal motivation and willingness to change cannot compensate for the lack of quality and proven tools for work. The introduction of tasks related to sustainable development contributes to the professional growth of teachers, expands their subject-methodological competence. Literature [8,10,17,18] and interviews also revealed that the use of real-world data-based tasks, mathematical modelling, digital tools and group work increases student engagement and builds systems thinking, which is fully in line with the goals of sustainability education.

The next principle of the strategy is the development of professional communities, the formation of inter-university and international networks for the exchange of experience and joint development of materials. The results show that the sense of professional isolation mentioned by the respondents is a serious barrier to the implementation of sustainable development principles. The successful experience of developing the course "Green Turn with Math" and the planned Nordplus project clearly demonstrate that inter-university co-operation and the formation of professional communities are effective mechanisms for sharing experiences, developing innovative materials and overcoming feelings of isolation among teachers.

The transdisciplinary approach that mathematics as a "universal language" for analyzing and solving global problems is key to preparing students for an uncertain future, as reflected in the literature [3,4,6]. The results show that linking abstract mathematical concepts to real life and professional contexts not only increases students' interest in the subject but also builds up their ability to apply mathematical tools to analyze complex problems beyond the scope of a single discipline. Implementing this approach requires teachers to be willing to work in collaboration with colleagues from other fields, as well as to use project-based forms of work and cases based on real data.

The analysis confirms the conclusions of international studies that mathematics plays a fundamental role in solving sustainable development problems. The literature emphasizes that mathematics is not a "value-neutral" discipline but a universal language of modeling and analysis that allows us to understand and predict environmental, economic, and social dynamics [6,8]. Thanks to key tools such as statistics, mathematical modeling, and optimization methods, it is possible to estimate CO₂ emissions, analyze resource use, predict population growth, and develop risk reduction strategies [13,19].

Interviews conducted as part of this study confirm these findings. Mathematics teachers emphasized that this discipline helps students develop critical and systematic thinking, learn to translate real-world problems into mathematical models, and thus understand their long-term consequences. As the respondents noted, *"mathematics is a universal language*

of analysis and argumentation; it allows one to critically evaluate data, model and optimize the consequences of decisions" (P2), and *"all mathematics is the principles of sustainable development: critical thinking, working with real problems, working with data"* (P3). These observations echo UNESCO's position that mathematics education should not only develop abstract skills but also help students consciously apply them to analyze global issues [1]. According to the World Economic Forum's "The Future of Jobs Report 2018" [34], critical thinking is identified as one of the key cognitive competencies for achieving the Sustainable Development Goals, as it is necessary for analyzing complex interrelationships and making responsible decisions. Thus, the connection between mathematics and sustainable development can be traced at two levels. First, at the theoretical and applied level, where mathematics provides quantitative analysis and modeling of sustainable processes, as confirmed by scientific literature. Second, at the pedagogical level, where mathematics develops critical and systematic thinking in students, as confirmed by both our interviews and empirical research. Several studies show that critical thinking is a skill that can be acquired and significantly developed through university mathematics courses [35–37]. For example, pre- and post-testing with control groups demonstrate a positive correlation between metacognition and math scores [38], and statistics education can effectively develop students' critical thinking skills through various pedagogical approaches [39]. This empirical data complements our qualitative material and indicates that higher mathematics education does indeed contribute to the development of critical thinking. Taken together, these two levels show that mathematics not only can but should be considered an integral part of sustainable development.

The proposed conceptual framework (Figure 2) reflects a non-linear, cyclical process of integrating the principles of sustainable development into mathematics education. The recognition of the need for sustainability and the understanding of the transdisciplinary nature of mathematics reinforce each other: the identification of interdisciplinary links encourages the integration of sustainability principles, and the idea of sustainability itself encourages the expansion of these links beyond the boundaries of a single discipline. Central to the model is the realization of sustainability in mathematics teaching by linking mathematical knowledge to real-world and interdisciplinary contexts. This process is inevitably accompanied by the identification of emerging problems and the search for solutions. Each improvement triggers a new cycle, which ensures the continuous adaptation of the approach to changing conditions. Thus, the model combines two interrelated cycles aimed at content reorientation and continuous improvement, thus creating a basis for sustainable development of mathematics education and sustainable employability in the future. Sustainable employability is one of today's complex challenges, which pedagogy approaches from a broader perspective of open participation, taking into account students' real experiences, emotions, and attitudes, and their relationship to the level of sustainability achieved in society. It is conceptualized as a multidimensional phenomenon manifesting across economic, social, cultural, and environmental domains. At the core of the sustainable employability model lies a pedagogical conception of experience and self-identity, linked to the formation of an evolving individual prototype shaped by both personal and shared life experiences. The integration and synthesis of experience and self-identity drive developmental change, thereby contributing to the achievement of sustainable employability [40].

Based on the challenges identified and the solutions proposed, future research could focus on developing and evaluating the effectiveness of specific teaching modules and materials adapted to different mathematical disciplines, as well as on studying the long-term impact of integrated programmes on students' competences for sustainable development. It

is also relevant to study institutional mechanisms for supporting teachers and overcoming the rigidity of curricula.

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